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Economics of Weed Management: Principles and Practices[1]

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Abstract: Weed scientists and invasive plant biologists must find cost-effective, ecologically based methods to manage undesirable plants. Economic analyses are needed for management, policy making, and setting research priorities. The fundamental economic principle for weed management is simple: act only if the benefits exceed the costs. Implementation of the principle is difficult, however, with the many and typically uncertain costs and benefits of management. The economic threshold is a well-known but not practical implementation of this fundamental economic principle. However, adoption of the threshold concept has spurred the development of decision models and use of methods of decision analysis. With these tools, scientists have quantified some risks of management and the value of information about the weed population in a field for management decisions or the value of specific information about weed biology for identifying new management strategies. Meaningful analysis for economic weed management is currently limited by lack of understanding of weed population and spatial dynamics and problematic communication between weed scientists and agricultural economists.

Additional index words: Decision analysis, economic analysis, economic threshold, risk, value of information.

INTRODUCTION

Weed scientists and invasive plant biologists have the same objective: developing strategies to manage undesirable plants based on fundamental ecological and economic principles. These scientists must both discover and implement the fundamental principles of ecology. In contrast, economic principles for management of undesirable plants are known. The task of scientists is then to identify analyses and tools that will lead to cost-effective management. Economics comprise just a small component of research by weed scientists and agricultural economists. In 2002 and 2003, only 4% of articles in the major journals for weed science[3] and none in three major journals of agricultural economics[4] included economic analysis of weed management. However, progress in applying economic principles by both researchers and managers has been spurred by the innovation of decision models for weed management in crops. Knowledge of the design of decision models, lessons learned from users of these models, and economic analyses using these models could help invasive plant biologists apply economic principles for both management and research strategies.

ECONOMIC PRINCIPLES

The fundamental economic principle for weed management is simple: act only if the benefits exceed the costs (King et al. 1998). Specific applications require slight variations of this principle. If there are many potential actions, such as choosing among eradication, containment, suppression, or doing nothing, the decision rule is choose the action that maximizes benefits minus costs (assuming benefits exceed costs). If the alternatives are more continuous than discrete, such as choosing herbicide rate or sampling intensity, the rule is use ‘‘more’’ only if the benefits exceed the costs.

Although the economic principles for choosing weed management are known and straightforward, implementation of these principles is not. There are many costs and benefits of weed management, and it is difficult to describe these on a common scale to consider trade-offs. Typically, economic analyses have included only costs and benefits of weed management that directly affect the

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[3] Agricultural Systems, Weed Science, Weed Technology, and Weed Research.

[4] American Journal of Agricultural Economics, Review of Agricultural Economics, and Australian Journal of Agricultural Economics.

decision maker and what he or she considers when selecting management. For example, a decision maker may consider how management affects crop quality and yield, how much time will be required, future weed problems, health risks, and the number of weeds that neighbors will see in his fields. However, significant outcomes may be effects on others that the decision maker does not consider when choosing weed management (Auld et al. 1987), such as further spread of the weed, herbicide drift, health of fish and wildlife, erosion, and water quality.

The most significant costs and benefits will be influenced by the level of decision making (Moore 1996), the possible actions, and the factors affecting the consequences of management. Scientific evidence to identify the most significant costs and benefits for an analysis is rare. An undesirable but necessary practice of weed scientists and economists has been to include outcomes in analyses based more on the feasibility of prediction and comparison than their significance. Comparison is a major constraint for the critical need to make trade-offs between economic and environmental outcomes. Indices have been developed to describe the environmental and health risks of different herbicides (Hoag and Hornsby 1992; Lui et al. 1995). However, the trade-off between management costs or yield losses and units of an index is not clear.

PRACTICES

Economic Thresholds. An economic threshold for managing weeds in crops is the density of a weed that will cause a loss equal to the cost of control (Cousens 1987). Therefore, act only if weed density is greater than the economic threshold. This threshold is calculated by comparing the value of prevented yield loss from weed competition in the current season with the cost of a herbicide application (Coble and Mortensen 1992). A related concept is the economic optimum threshold that accounts for both immediate and future costs and benefits of management (Jordan 1992). Preventing seed production can minimize future weed problems, but weed control in the future may be less expensive because a dollar spent or earned in the future is worth less than a dollar today. The threshold may be lower (Bauer and Mortensen 1992) and optimum management much different with a longer term perspective on weed management (Jones and Medd 2000; Munier-Jolain 2002).

Weed scientists adopted the idea of an economic threshold from entomologists, but the economic threshold has not become the practical decision-making tool that it is for insect management (Czapar et al. 1997). The significance of the economic threshold in weed science is as a concept that emphasizes doing nothing as a management option and highlights the necessary coupling of economics and biology. Introduction of this concept has led to more discussion on the economics of management between researchers and managers. Moreover, this concept spurred the development of weed management decision models and the application of decision analysis for identifying cost-effective management and research strategies.

Weed Management Decision Models. Weed scientists developed decision models to help growers apply economic thresholds for management of specific fields, but the real value of these models is giving growers access to research data and the knowledge of experts and further integrating these data and expertise into information growers need to choose for cost-effective management (Wilkerson et al. 2002). Most models are for helping growers choose among different herbicide applications for postemergence weed control in major field crops (models are reviewed in Wilkerson et al. 2002). As with the economic threshold, typically the cost of the herbicide application is compared with the value of potential yield loss from weed competition in the current season. The yield loss is predicted from a user's description of the average weed composition in a field. Because weed scientists know that a user may have other objectives for weed management than maximizing returns, the user can view the cost–benefit analysis for all possible actions (Wilkerson et al. 2002).

Few research programs have been able to afford the cost of designing, programming, debugging, and distributing a decision model and then later updating the model for new technology. Models must be modified for regional variation in weed ecology and management practices. However, some models were designed with a module for altering parameters and possible actions without programming (Bennett et al. 2003; Wiles et al. 1996). More growers have had the opportunity to use decision models because weed scientists in several states have been willing to undertake the task of compiling data, determining parameters, and testing models for users in their states (i.e., Monks et al. 1995).

Management decision models have not been as widely adopted as anticipated. In 2003, just 1,500 copies of two established decision models for major field crops were used (A. Martin, personal communication; G. Wilkerson, personal communication). Growers cannot use these models until there are cost-effective methods to obtain information about the weed population in a field

(Schweizer et al. 1998), and there are other biological and socioeconomic obstacles to adoption of models as a field tool (Martin et al. 1998). However, a decision model has value if decision makers manage better with the model than without. Decision makers have found models useful for being alerted to new herbicide treatments, finding treatments for unfamiliar weeds, and identifying a set of cost-effective control options to choose among for anticipated weed problems during the season when they do not have time to use the model (Wilkerson et al. 2002). Models also are used to learn about the characteristics of different options before the growing season and to educate students about ecological and biological principles of weed management.

Decision models have been an effective research tool to evaluate weed management strategies and policy and to set research priorities. With the bioeconomic simulation models embedded in decision models, scientists have been able to do new types and more practical economic analyses, especially when using methods of decision analysis. These methods provide a decision maker's perspective of what are the best management and information needed to choose the best option. Researchers have more typically focused on the significance and required accuracy of biological predictions. The bioeconomic models embedded in decision management models are used to both predict biological and economic outcomes of management and model the decision makers' preferences for outcomes.

Decision Analysis. Decision analysis is a set of methods developed by economists, engineers, and statisticians for making complex, risky decisions (Hardaker et al. 1997). Complexity arises from multiple options and several and sometimes conflicting objectives. Clearly, growers do informal decision analysis when making management decisions. The primary objective may be maximizing profit, but a grower also may want to control a newly invading weed or minimize drift of herbicide into a neighbor's field. One management option may be more profitable than another, but the second may be faster, so the grower can go to a son's baseball game. A third more expensive option may control weeds more consistently over a range of environmental conditions. There is uncertainty about the species and relative importance of species in a field, the selling price of the crop, reliability of equipment, and all outcomes influenced by the weather.

The process of decision analysis is breaking down a risky decision into two components, alternative actions and preferences for consequences of actions, and then combining these into an analytical framework to identify the best choice (Hardaker et al. 1997). All components of a decision are recognized and described. These are sources of uncertainty, probabilities of outcomes, multiple consequences of outcomes, the decision maker's preferences for consequences, and the choice criterion representing the decision maker's values (U.S. Congress, Office of Technology Assessment 1993). Fortunately, decision making can be improved without addressing all these components (Hardaker et al. 1997). In fact, weed scientists have used primarily just two methods: accounting for risk and calculating the value of information.

Risk of weed management is a consequence of biological variation, sampling errors, and inaccurate predictions of the benefits and costs of weed management. Growers may use herbicides more to manage risk than to maximize profit (Olson and Kidman 1992), and the adoption of new management strategies may be hampered by a perception of higher risk (de Buck et al. 1999). Uncertainty about the outcome of management can be accounted for in a decision by choosing the action with the highest ''expected benefit'' rather than the benefit for a most likely or average outcome. Expected benefit is the sum of the outcome of action, such as profit, for a situation weighted by the probability of that situation occurring (Hardaker et al. 1997).

A detailed probability distribution is not needed to consider risk in a decision, and the distribution may be constructed from data or the decision maker's opinion (Figure 1). Suppose a grower must decide whether to spray a field today, he chooses based on the simple economic threshold. Several days ago, a scout reported that there were no weeds in a field. However, there was rain since then, so weeds may have emerged, but the grower does not have time to scout the field again. On the basis of the criterion of expected benefit calculated from his own opinion of the possible weed emergence since the scout's observation, the grower would choose to spray the field to prevent an unlikely but significant loss from a moderate population (Figure 1).

Information about the composition and spatial distribution of a weed population is valuable for management. Also, better understanding of some ecological processes may be more cost-effective for identifying optimal management strategies than other processes. Weed scientists have been able to investigate what and how much information is most cost-effective for both management and research with the decision analytic concepts of the ''value of information'' and ''loss'' (King et al. 1998; Wiles et al. 1992). Information has value only if it causes

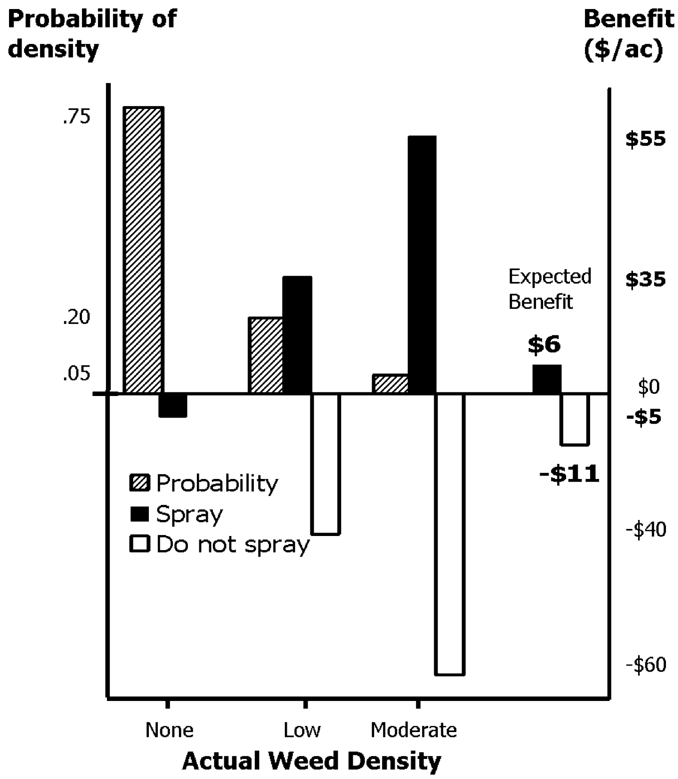

Figure 1. A probability distribution of three points is used to calculate the expected benefit of weed management to account for the risk of weed emergence since the scout observed the field. The probability distribution is the grower's opinion of weed emergence given rain since the scout's observation of no weeds. Application of the herbicide costs US$5, and efficacy is 100%.

a decision maker to do something different than would have been done without the information. Scientists typically quantify the value of sampling information based on the accuracy of density estimates; however, a management strategy may be optimal for a variety of weed populations. Growers are primarily interested in sampling errors that lead to not choosing the optimal action, and the value of the additional sampling information is determined by the consequences of choosing the wrong action, such as loss of profit. The decision analytic concept of ''loss'' is one way to quantify the value of information that reflects the decision makers' perspectives (Wiles et al. 1992).

Decision models have been used with methods of decision analysis to evaluate sampling protocols (Jordan et al. 2003), compare management strategies (King et al. 1986) and the risk of strategies (de Buck et al. 1999), estimate the value of site-specific weed management (Oriade et al. 1996; Wiles et al. 2003), consider tradeoffs between economic and environmental outcomes of weed management (Hoag and Hornsby 1992; Lui et al. 1995; Swinton et al. 2002), determine whether information about the weed population in a field is valuable and cost-effective for improving decision making (Pannell 1994; Swinton and King 1994), and even assess the value of bioeconomic models to growers (reviewed by King et al. 1998). Other studies demonstrate the potential use of methods of decision analysis to describe the risk of sampling errors (Faechner et al. 2002; Wiles et al. 1993), assess the economic effect of a herbicide ban (Swinton et al. 1995), prioritize research (Wiles et al. 1992), or identify the best situations for use of site-specific strategies (Oriade et al. 1996).

OBSTACLES

Weed scientists and invasive plant biologists face the same major obstacles to meaningful analysis of the economics of weed management. Foremost is the lack of reliable data and insufficient understanding of weed population and spatial dynamics (Jordan 1992; Schweizer et al. 1998). A contributing factor to the lack of data for economic analysis of weed management is the emphasis of weed scientists on experiments and testing for differences between treatments and agricultural production and the emphasis of economists on estimating relationships between inputs and outputs with mathematical models (Dillon 1977). Weed scientists developing decision models have been innovative in substituting expert opinion for unavailable experimental data such as the relative competitiveness of weed species and emergence patterns. Decision models have been evaluated by comparing recommendations of a decision model with experts' recommendations for the same situation (G. Wilkerson, personal communication). Substituting expert opinion for experimental data works best for easily observed biological processes (i.e., emergence patterns vs. number of seeds produced), and when there are several experts and structured methods are used to elicit opinions.

These differing research approaches also hinder effective communication between agricultural economists and weed scientists. These disciplines have different vocabularies for economic concepts, principles, and methods. For example, yield loss equations of weed scientists are production functions to agricultural economists. Consequently, exchange on research methods, data and results, collaboration, and even recognition of possible synergism of collaboration are too limited. Information on economic principles and analyses is rarely targeted for both biologists and economists with a few exceptions (Auld et al. 1987; Hardaker et al. 1997; King et al. 1998; Pannell 1988).

Weed scientists have identified key elements for successful collaboration with economists. Economic analyses and tools for decision making, most useful to decision makers, have involved the cooperation of an agricultural economist willing to learn the basics of weed science, a weed ecologist–biologist who conducts innovative field experiments and works closely with managers, and a weed scientist with training in mathematical modeling or applied economics. This type of collaboration is possible only when the project is professionally challenging and rewarding for all participants (S. M. Swinton, personal communication). Routine budgeting or production function analyses are not publishable in most disciplinary journals of agricultural economics. Economists must be willing to make the extra effort to describe models developed from biological data of their colleagues in terms appropriate for publication in journals of weed science. Economic analyses of invasive weed management will require models of weed biology, data on distribution of undesirable plants, and consideration of trade-offs among economic and environmental outcomes. There will be many opportunities for collaboration between invasive plant biologists and agricultural production and natural resource economists.

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